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Effects of aerobic exercise and cognitively engaging exercise on cardiorespiratory fitness and motor skills in primary school children: A cluster randomized controlled trial

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ABSTRACT

This paper examined effects of two interventions on cardiorespiratory fitness and motor skills, and whether these effects are influenced by baseline levels, and dose of moderate-to-vigorous physical activity (MVPA) during the intervention. A cluster randomized controlled trial was implemented in 22 schools ($n = 891$; 9.2 ± 0.7 years). Intervention groups received aerobic or cognitively engaging exercise (14-weeks, four lessons per week). Control groups followed their regular physical education programme. Cardiorespiratory fitness, motor skills and MVPA were assessed. Multilevel analysis showed no main effects on cardiorespiratory fitness and motor skills although the amount of MVPA was higher in the aerobic than in the cognitively engaging and control group. Intervention effects did not depend on baseline cardiorespiratory fitness and motor skills. Children with a higher dose of MVPA within the intervention groups had better cardiorespiratory fitness after both interventions and better motor skills after the cognitively engaging intervention. In conclusion, the interventions were not effective to enhance cardiorespiratory fitness and motor skills at a group level, possibly due to large individual differences and to a total dose of MVPA too low to find effects. However, the amount of MVPA is an important factor that influence the effectiveness of interventions.

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KEYWORDS

Physical activity; physical education; exercise intervention; elementary school

Introduction

Cardiorespiratory fitness and motor skills are important indicators for children's physical health and development. Cardiorespiratory fitness is defined as the ability of the circulatory and respiratory systems to supply oxygen during sustained physical activity (Corbin et al., 2000). Low cardiorespiratory fitness levels have shown to be related to cardiovascular disease risk factors, increased body fatness, and hypertension in children and adolescence (Ortega et al., 2008). Motor skills encompass several aspects of movement competency (Lopes et al., 2012). Motor skills acquired during early childhood form the basis for advanced movements and sport-specific skills as well as for a physically active lifestyle (Clark & Metcalfe, 2002). Unfortunately, significant declines in cardiorespiratory fitness and motor skills have been shown in children since the 1980s (Runhaar et al., 2010; Timmermans et al., 2017; Tomkinson et al., 2017). Therefore, there is a need for interventions that stimulate both cardiorespiratory fitness and motor skills.

Primary schools are ideal environments to implement interventions (Gallotta et al., 2015), since more than 90% of children worldwide attend primary school (UNESCO Institute for Statistics [UIS], 2018). Several studies have investigated the

effects of school-based interventions separately for cardiorespiratory fitness and motor skills. A systematic review by Sun et al. (2013), which was based upon ten randomized controlled trials, showed strong evidence for effects of school-based physical activity interventions on cardiorespiratory fitness. The interventions consisted of aerobic activities (e.g., running, jumping, dancing activities) and the duration of the interventions varied between 8 and 36 weeks. 80% of the large higher quality RCTs were effective. The effective studies delivered a high dose of physical activity (two 60-minute sessions of MVPA per week was considered as a high dose). Sun et al. (2013) concluded that improved cardiorespiratory fitness was determined by a combination of intensity, frequency and duration and that only interventions with a high dose of physical activity were effective to improve cardiorespiratory fitness.

One characteristic that seems important to enhance cardiorespiratory fitness is physical activity at moderate-to-vigorous intensity (MVPA). School-based physical activity, such as physical education, provides an opportunity for children to engage in MVPA. A meta-analysis by Hollis et al. (2016) showed that children are on average 45% of the total time engaged in MVPA during physical education lessons, although percentages vary

between studies (ranging from 11% to 89%). The meta-analysis by Lonsdale et al. (2013) showed that levels of MVPA during physical education can be increased by interventions focusing on high intensity activities. Therefore, an increase in the number of physical education lessons per week and intervention strategies focusing on high intensity activities enhances the amount of MVPA and this can subsequently lead to higher cardiorespiratory fitness.

The meta-analysis by Morgan et al. (2013), which evaluated school-based motor skill interventions, showed a large effect size for motor skills. Twenty-two studies were included, of which only six studies were randomized controlled trials. All studies reported intervention effects for more than one of the motor skills measured and 12 of the studies found overall effects on motor skill. Process-oriented outcomes, such as the Test of Gross Motor Development (TGMD), were the most commonly used measures to evaluate motor skills. The included interventions varied in duration between 4 weeks and 3 years and consisted of enhanced physical education vs traditional education or enhanced physical education and additional increased time in physical education, generally with multiple lessons per week. Intervention programmes focused on individual practices and self-testing activities, however, there was a lack of detailed description of the interventions in the studies included in this meta-analysis. Furthermore, most studies did not detail the dose of physical education that children received during the interventions, while previous studies have shown that effects of interventions are influenced by characteristics of children, such as baseline levels and the individual amount of MVPA during interventions (Pesce, 2009). Therefore, it is difficult to determine the intervention and individual characteristics that are related to the effectiveness of interventions.

Motor skills can be improved by activities in which children could repeatedly practice and develop motor skills in several ways (McKenzie, 2007). Individual activities, such as coordinative exercises like balancing, running, jumping, throwing and catching, yield opportunities to learn motor skills. Team games provide opportunities to apply motor skills in a competitive and strategic way (Best, 2010). Such games are cognitively engaging, which is defined as *“the degree to which the allocation of attentional resources and cognitive effort is needed to master difficult skills”* (Tomprowski et al., 2015). The combination of individual activities to practice motor skills and cognitively engaging games to apply motor skills in complex situations might enhance motor skills in children. Although positive effects of cognitively engaging exercise have been found for cardiorespiratory fitness (Schmidt et al., 2015), no studies have examined the effects of cognitively engaging exercise on motor skills.

In the current study, an aerobic intervention – with the aim to increase the amount of MVPA – and a cognitively engaging intervention – with the aim to increase the amount of motor skill challenges – were developed and implemented in 14 weeks of primary school physical education. The two intervention programmes were performed four times per week, instead of the regular physical education lessons provided twice per week. The study had three aims. The first aim was to investigate the main effects of the aerobic intervention and

the cognitively engaging intervention on cardiorespiratory fitness and motor skills. The second aim was to investigate whether intervention effects were dependent on baseline cardiorespiratory fitness and motor skills. The final aim was to investigate whether there was a dose-response effect of the total dose of MVPA during the interventions on cardiorespiratory fitness and motor skills. We expect that both intervention programmes with the extension of physical education compared to standard frequency of physical education classes and increasing the time in MVPA (in the aerobic intervention) will lead to increased levels of cardiorespiratory fitness and motor skills. Additionally we expect that children with lower baseline levels would benefit more from the interventions compared to children with higher baseline levels as there is more room for improvement in children with lower baseline levels (Kristensen et al., 2010; Logan et al., 2012).

Methods

Participants

This study was part of a cluster randomized controlled trial in the Netherlands (“Learning by Moving”), assessing the effects of two interventions on physical and cognitive outcomes, academic achievement, brain structure, and brain function in primary school children. A cluster power analysis with 0.40 as effect size (Davis et al., 2011) resulted in a required sample of ≥ 40 classes (grade three and four) across 20 schools (average cluster size = 25; power = 0.80; $\alpha = 0.05$; 1-tailed; intraclass correlation = 0.10; Spybrook et al., 2011). To take into account the possibility that schools might withdraw from participation, third and fourth grade children from 24 schools were included in the study. Cluster-randomization was performed in two steps. Firstly, pairs of schools were made based on the school size and it was randomly determined which intervention a pair of schools received. Secondly, it was randomly determined within the first school of the pair which class (third or fourth grade) received the intervention and which class served as the control group. The other school in the pair received the same intervention, but in the opposite grade class.

Just before the start of the study, two schools withdrew permission, due to organizational difficulties. Finally, children from grade three and four classes across the 22 primary schools were recruited for the study. School directors and parents or guardians of 891 children gave written consent for their children to participate. Figure 1 shows the total number of children in each stage of the study and for each outcome variable. Reasons for missing values were school absence on testing days, moving to another school, or injuries. This study was approved by the ethical board of the Vrije Universiteit Amsterdam (VCWE-S-15-00197), and registered in the Netherlands Trial Register (NL5194).

Instruments

Cardiorespiratory fitness and motor skills

Cardiorespiratory fitness was measured using the 20-metre Shuttle Run Test from the Eurofit test battery (20-m SRT; Adam et al., 1988). Validity and reliability of the 20-m SRT have shown to

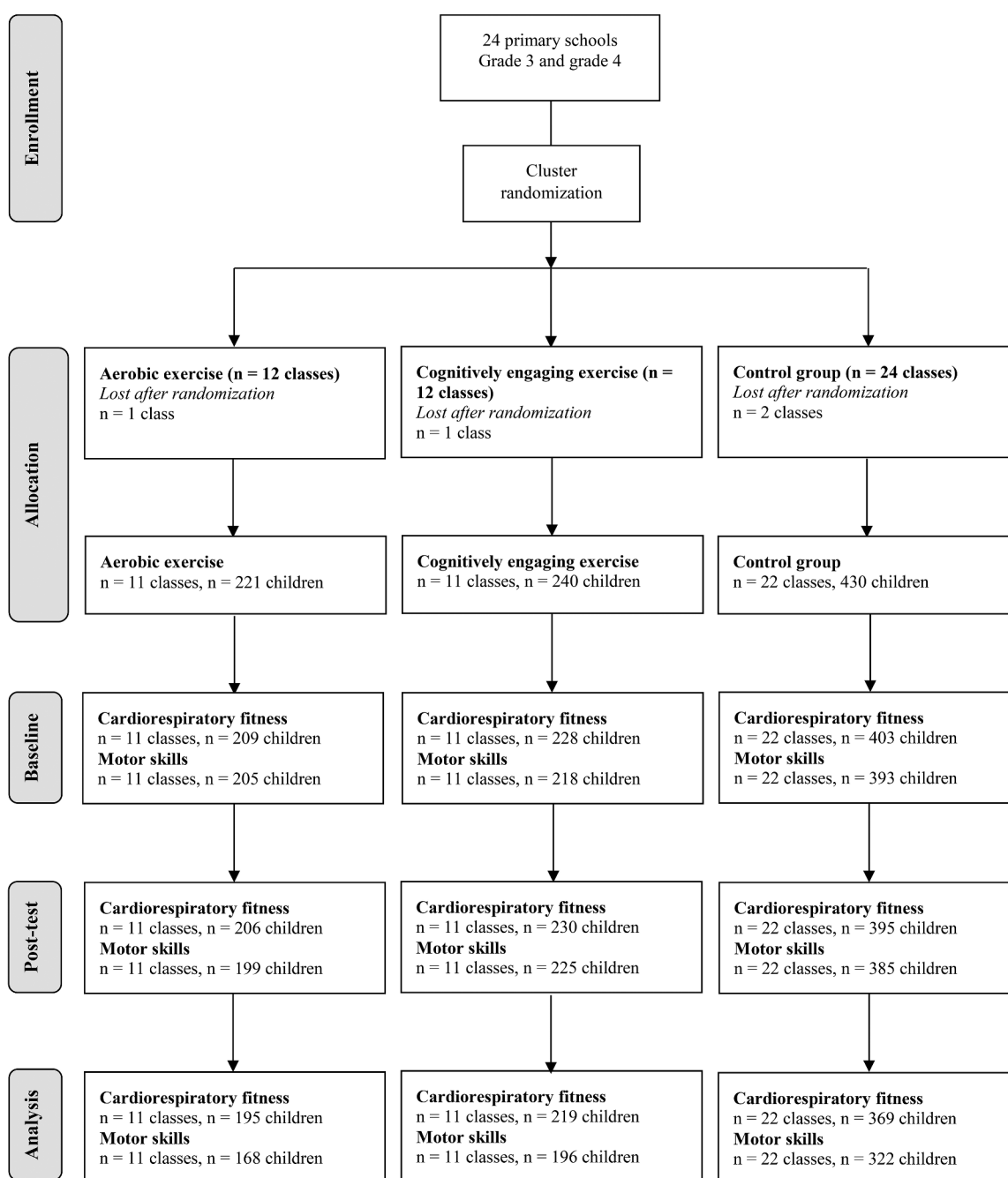


Figure 1. Flow chart with the number of children in each stage of the study.

be adequate in children (Leger et al., 1988). Gross motor skills were assessed using three subtests (jumping sideways, moving sideways, and backwards balancing) of the Körper Koordinationstest für Kinder (KTK; Kiphard & Schilling, 2007). The KTK originally consists of four subtests, but a recent study has shown substantial agreement between three subtests and the original four subtests (Novak et al., 2017). Additionally, one item of the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2) was used to include a measure for ball skills (Bruininks, 2005). These test batteries were used, because they have shown to be reliable and valid for primary school children (Bardid et al., 2019; Bruininks, 2005; Deitz et al., 2007; Kiphard & Schilling, 2007). Furthermore, the instruction and demonstration are simple and short and these tests are easy to administer after training (Cools et al., 2009).

Moderate-to-vigorous physical activity (MVPA)

During two physical education lessons (one in the first week and one in the last week of the intervention period), children in *all* study conditions wore accelerometers on the right hip to obtain the amount of MVPA (ActiGraph GT3x+, Pensacola, FL, USA). The accelerometer measures accelerations in three directions with a frequency of 100 Hz. Only data from the vertical axis were used. Analyses were performed in data analysis software ActiLife (v6.8.2). An epoch length of 1 s. was used (Trost et al., 2011). A cut-off point of >2296 counts/min was used as a measure for MVPA (Evenson et al., 2008). Time in MVPA and percentage of total lesson time in MVPA were calculated.

Implementation measures

Average percentage of the total lesson time in MVPA over the two lessons was calculated as an implementation measure. The duration of the physical education lessons was obtained during the two lessons in which MVPA was measured in each study condition. The intervention teachers logged the number of intervention lessons delivered and the absence of the children during the interventions. This was used to calculate the number of intervention lessons followed by each child. The total dose of MVPA in the two intervention groups was estimated by multiplying the mean time in MVPA over the two physical education lessons with the total number of intervention lessons followed by a child. The total dose of MVPA was used to investigate the dose response relations in the intervention groups.

Procedure

Children in the intervention groups followed the aerobic intervention or the cognitively engaging intervention four times per week for a period of 14 weeks during the school year (2016/2017). The 14 week intervention period was chosen, because previous studies have shown positive effects using intervention periods for at least 14 weeks (Sun et al., 2013). The interventions replaced their normal physical education lessons (two lessons per week) and two additional physical education lessons were scheduled within the school academic timetable. We increased the number of physical education lessons, since there is evidence that a high dose of intervention is needed to obtain improvements in cardiorespiratory fitness and motor skills (Morgan et al., 2013; Sun et al., 2013). The lessons consisted of a warm-up phase of 10 minutes and a core phase of 20 minutes.

The *aerobic intervention* consisted of specifically designed activities targeted at MVPA intensity. The focus was on highly repetitive and automated exercises, such as circuit training, relay games, playing tag, and individual activities like running or doing squats. The *cognitively engaging intervention* consisted of team games or exercises that require complex coordination of movements, strategic play, cooperation between children, anticipating the behaviour of teammates or opponents, and dealing with changing task demands (Best, 2010). Children played adapted versions of games such as dodgeball, basketball, or soccer (Tompsonowski et al., 2015). Complex rules were included in the games, in a way that children were constantly challenged to think about their actions and movements. Additionally, exercises such as balancing, climbing, clambering, throwing and catching were included. The complexity of the games and exercises increased during the intervention period. Children in the *control group* followed their regular physical education lessons twice a week.

The interventions were provided by certificated physical education teachers recruited for this study, who received training and a manual containing a detailed description of the interventions. Cardiorespiratory fitness and motor skills were assessed at baseline and post-test, within a period of two weeks before and after the intervention. Children were tested by trained research assistants using standardized protocols. Motor skills were individually assessed during one or two (depending on the class size) physical education lessons in circuit form with tests administered in a random order. The

20-m SRT was conducted during a separate physical education lesson and was administered in groups of up to 15 children.

Data analysis

Initial analyses were performed in IBM SPSS Statistics version 25.0. Outliers ($z \leq -3.29$ or ≥ 3.29) were replaced with a value one unit greater than the next non-outlier value (Tabachnick & Fidell, 2007). The three study conditions were compared based on background variables (age, sex, grade, BMI, socioeconomic status [SES]), on cardiorespiratory fitness and motor skills at baseline and on implementation measures using a one-way analysis of variance (ANOVA), a χ^2 test, or an independent sample t-test where appropriate.

A principal component analysis on the standardized scores of the motor skill tests was performed (baseline and post-test combined) to calculate a Bartlett factor score. The four motor skill components loaded highly (> 0.6) onto one factor and explained 52.0% of the total variance. This factor was used in the analysis as a measure of motor skills. Supplementary Table 1 shows the correlation matrix and the factor loadings of the principal component analysis.

Main analyses were performed using Multilevel regression analysis (MLwiN version 2.35). Post-test cardiorespiratory fitness and motor skills were used as dependent variables in the models. A random intercept was added to the model for each class (level 2) and each child (level 1). The first model contained only covariates (sex, grade, age, BMI, SES and corresponding baseline score). Covariates that did not significantly contribute to the model were excluded by means of backward stepwise deletion. Study condition was added to investigate main effects of the interventions on cardiorespiratory fitness and motor skills as compared to the control condition as well as the aerobic intervention compared to the cognitively engaging intervention. To investigate whether intervention effects depended on the corresponding baseline score, the interaction between baseline and study condition was added. To investigate the dose-response effect of the total dose of MVPA on the outcome variables in the intervention groups, the total dose of MVPA was added followed by the interaction between the total dose of MVPA and the study condition. To evaluate model fit, the deviance of the model with the variable of interest was compared to the deviance of the model without the variable of interest using a χ^2 difference test. A false discovery rate (FDR) correction was applied to the predicted variables in the model to account for multiple testing (q -values are shown for values after FDR correction; Benjamini & Hochberg, 1995). Level of significance was set at 0.05 (one-sided) and 90% Confidence intervals (CI) were reported.

Results

Table 1 shows the characteristics of the children in each study condition. The proportion of grade three children and age differed significantly between the study conditions, due to the two schools that dropped-out. The three study conditions did not differ on pre-test cardiorespiratory fitness, $F(2,813) = 0.11$, $p = 0.90$, and pre-test motor skills, $F(2,837) = 1.22$, $p = 0.30$ (Table 2).

Table 1. Descriptive statistics of the included population.

	Aerobic exercise group	Cognitively engaging exercise group	Control group	p-value
Age ^a (years); range	9.3 ± 0.7; 7–10**	9.1 ± 0.6; 7–10	9.2 ± 0.7; 7–11	< 0.01 ^c
Sex ^b (% boys)	48.9	47.1	50.9	0.62 ^d
Grade ^b (% 3rd grade)	44.3*	51.2* [#]	54.7	< 0.05 ^d
Height ^a (cm)	139.4 ± 6.6	138.6 ± 7.0	138.8 ± 6.6	0.41 ^c
Weight ^a (kg)	33.0 ± 6.0	32.7 ± 6.8	32.1 ± 6.3	0.18 ^c
BMI ^{a,e} (kg/m ²)	16.9 ± 2.4	16.9 ± 2.5	16.6 ± 2.4	0.14 ^c
Overweight ^{b,f} (n (%))	30 (13.6)	32 (13.3)	47 (10.9)	0.41 ^d
Obesity ^{b,f} (n (%))	5 (2.3)	8 (3.3)	11 (2.6)	
SES ^{a,g}	4.4 ± 0.9	4.7 ± 1.1 [#]	4.5 ± 1.0	0.01 ^c
Participation in organized sports (%) ^h	86.8	89.6	89.9	0.50 ^d
Participation in organized sports (minutes/week) ^h	147.1 ± 136.2	141.9 ± 112.4	150.1 ± 103.5	0.69 ^c

^amean ± standard deviation; ^bn(%); ^cOne-way analysis of variance; ^dNon-parametric χ^2 test; ^eBody mass index, calculated by weight(kg)/height(m)²; ^fbased on reference values by (Cole & Lobstein, 2012); ^gSocioeconomic Status, calculated by the average education level of both parents (Schaart et al., 2008); ^hpercentage of children that participate in organized sports, obtained by a parent questionnaire; ⁱParticipation in sports, defined as weekly participation in organized sports in minutes, not including physical education, transport to school and playing outside, obtained by a parent questionnaire; *Significantly different from control group ($p < 0.05$); **Significantly different from the control group ($p < 0.01$); [#]Significantly different from the aerobic exercise group ($p < 0.05$); ^{##}Significantly different from the aerobic exercise group ($p < 0.01$).

Table 2. Overview of baseline and post-test scores on cardiorespiratory fitness and motor skills for the three study conditions.

	N	Aerobic exercise group	N	Cognitively engaging exercise group	N	Control group
Cardiorespiratory fitness ^a	Baseline 209	4.6 ± 1.8	228	4.3 ± 1.8	403	4.5 ± 1.9
	Post-test 206	5.3 ± 2.2	230	5.1 ± 2.0	395	5.1 ± 2.1
Jumping sideways ^b	Baseline 211	49.3 ± 15.2	230	48.1 ± 15.4	405	49.5 ± 15.8
	Post-test 205	61.5 ± 15.6	229	55.6 ± 16.0	396	57.4 ± 16.3
Moving sideways ^c	Baseline 211	34.1 ± 9.3	232	35.6 ± 9.2	407	33.3 ± 8.8
	Post-test 206	37.5 ± 8.2	231	37.0 ± 8.9	405	37.5 ± 9.4
Backwards balancing ^d	Baseline 212	40.1 ± 12.4	232	40.7 ± 13.6	410	40.7 ± 14.2
	Post-test 206	44.6 ± 13.7	229	45.0 ± 13.3	399	44.1 ± 13.6
Upper limb coordination ^e	Baseline 211	31.1 ± 5.2	223	29.9 ± 5.3	403	31.0 ± 5.2
	Post-test 207	32.4 ± 4.1	230	31.2 ± 4.5	402	32.1 ± 4.3
Gross motor skills (factorscore) ^f	Baseline 205	-0.22 ± 1.0	218	-0.26 ± 1.0	393	-0.25 ± 0.9
	Post-test 199	0.39 ± 0.9	225	0.16 ± 1.0	385	0.23 ± 1.0

Values are expressed as mean ± standard deviation; ^aNumber of completed stages; ^bTotal number of jumps in 15 seconds in two trials; ^cTotal points in 20 seconds of two trials; ^dTotal number of steps on three wooden beams (resp. 6 cm, 4.5 cm, and 3 cm wide), with three trials per beam and a maximum of eight steps per trial, resulting in a maximum score of 72; ^eTotal score of seven activities executed with a tennis ball (maximum score is 39 points); ^fBartlett factor score calculated from the standardized scores of the four motor skill tests (jumping sideways, moving sideways, backwards balancing, and upper limb coordination; baseline and post-test combined).

Implementation

Table 3 shows the mean duration of the physical education lessons, the percentage of time in MVPA, the total number of lessons followed by the children, and the total dose of MVPA. The total dose of MVPA was used for the dose-response effects of MVPA and was significantly higher in the aerobic intervention (9.3 ± 2.5 hours) compared to the cognitively engaging intervention (7.0 ± 2.1 hours), $t = 9.95$, $p < 0.01$, 90% CI [1.93–2.69].

Main effects of the interventions

Table 4 shows the results of the multilevel analysis assessing the effects of the aerobic intervention and the cognitively engaging intervention on cardiorespiratory fitness and motor skills. The addition of study condition did not significantly improve the model for cardiorespiratory fitness, $\Delta\chi^2(2) = 1.57$, $p = 0.46$, and motor skills, $\Delta\chi^2(2) = 2.89$, $p = 0.24$, indicating no effects of aerobic exercise and cognitively engaging exercise as compared to the control group, and no difference between the two interventions.

Effects of baseline levels

The addition of the interaction between study condition and baseline cardiorespiratory fitness did not significantly improve

the models for cardiorespiratory fitness, $\Delta\chi^2(2) = 5.40$, $p = 0.07$, and motor skills, $\Delta\chi^2(2) = 1.62$, $p = 0.44$. These results indicate that effects of the interventions for cardiorespiratory fitness and motor skills did not depend on corresponding baseline score.

Dose-response effects of MVPA

The total dose of MVPA did significantly contribute to the model for cardiorespiratory fitness, $\Delta\chi^2(1) = 9.11$, $p < 0.01$ (Figure 2(a)). A higher dose of MVPA during the interventions was related to higher cardiorespiratory fitness at the post-test, $t = 2.97$, $q = < 0.01$, 90% CI [0.05–0.17]. The interaction between total dose of MVPA and condition did not significantly improve the model, $\Delta\chi^2(1) = 2.30$, $p = 0.13$, indicating that the effects of the total dose of MVPA on cardiorespiratory fitness did not differ between the aerobic intervention and the cognitively engaging intervention.

Total dose of MVPA did not significantly contribute to the model for motor skills, $\Delta\chi^2(1) = 0.06$, $p = 0.81$, but the addition of the interaction between total dose of MVPA and study condition improved the model, $\Delta\chi^2(1) = 5.43$, $p = 0.02$ (Figure 2(b)). There was a positive effect of the total dose of MVPA on motor skills in the cognitively engaging intervention, but not in the aerobic intervention, $t = 2.29$, $q = 0.02$, 95% CI [0.02–0.14].

Table 3. Implementation measures.

	Aerobic exercise group	Cognitively engaging exercise group	Control group – aerobic exercise group		Control group – cognitively engaging exercise group		Aerobic exercise group – cognitively engaging exercise group	
			Mean difference (90% CI)	p-value	Mean difference (90% CI)	p-value	Mean difference (90% CI)	p-value
Duration physical education lesson (minutes)	34.5 ± 3.7	39.2 ± 6.5	36.9 ± 5.6	<0.01 ^c	2.43 (1.73–3.13)	<0.01 ^c	–4.67 (–5.46 – –3.89)	<0.01 ^c
Amount of MVPA (percentage) ^a	34.9 ± 8.4	23.5 ± 6.1	27.9 ± 8.4	<0.01 ^c	–6.95 (–8.08 – –5.83)	<0.01 ^c	11.36 (10.08–12.65)	<0.01 ^c
Number of lessons followed by the child	45.6 ± 5.7	44.9 ± 7.1					0.76 (–0.22–1.77)	0.20 ^d
Total dose of MVPA (hours) ^b	9.3 ± 2.5	7.0 ± 2.1					2.31 (1.93–2.69)	<0.01 ^d

Values are expressed as mean ± standard deviation; MVPA = moderate-to-vigorous physical activity; CI = Confidence Interval; ^aAverage amount of MVPA of the two observed physical education lessons; ^bCalculated by multiplying the average time in MVPA with the number of lessons followed by the child; ^cOne-way analysis of variance; ^dIndependent samples t-test.

Discussion

This study showed no main effects of the aerobic intervention and the cognitively engaging intervention on cardiorespiratory fitness and motor skills in primary school children in grades three and four. Secondly, intervention effects did not depend on baseline scores of cardiorespiratory fitness and motor skills. Thirdly, a higher dose of MVPA was related to better cardiorespiratory fitness after both interventions and to better motor skills after the cognitively engaging intervention.

Children in the intervention groups followed – on average – 3.2 physical education lessons per week. While this is less than the prescribed frequency of four times per week, it proved possible to increase the number of physical education lessons in primary schools. In addition, it was shown that the level of MVPA during physical education can be increased: children in the aerobic intervention exercised on average 35% of the time in MVPA, which was significantly more than children in the control condition (28%) and in the cognitively engaging intervention (24%). These findings show that the dose of MVPA that children receive at school can be increased by changing the content and frequency of physical education lessons which confirms the findings in the meta-analysis by Lonsdale et al. (2013).

Both interventions showed no main effect on cardiorespiratory fitness. This is contradictory to our hypothesis and to previous studies showing that cardiorespiratory fitness can be improved by school-based physical activity interventions (Sun et al., 2013). The lack of significant effects at a group level may be explained by a combination of the duration, frequency and intensity of the interventions (Sun et al., 2013). Previous studies that were effective in improving cardiorespiratory fitness developed interventions with a duration of at least 14 weeks. Only the studies with a high dose of intervention (e.g., at least two 60-minute sessions of MVPA per week) showed improvements in cardiorespiratory fitness (Sun et al., 2013). We developed interventions that should have been delivered four times per week, but on average children followed 3.2 lessons per week. Furthermore, the intervention lessons in the aerobic intervention had a mean duration of 34.5 minutes and children exercised 34.9% of the time in MVPA. The lessons in the cognitively engaging intervention had a mean duration of 39.2 minutes and children exercised only 23.5% of the time in MVPA. Therefore, the total intervention dose may have been lower than the dose in previous interventions that have shown positive effects on cardiorespiratory fitness and this can explain why we did not find positive effects of our interventions. Additionally, children in our study are engaged in a high amount of physical activity in their leisure time (see Table 1). This might have led to a total dose of MVPA too low to find effects on cardiorespiratory fitness in a group of children that are already involved in structural sport activities.

However, although children within the intervention groups received equal instructions, the variation in MVPA between children within the intervention groups was high. We showed that more time in MVPA during the interventions was related to higher cardiorespiratory fitness after the interventions, which confirmed our hypothesis regarding the dose-response effects

Table 4. Results of the multilevel analysis for cardiorespiratory fitness and motor skills.

Fixed effects	Cardiorespiratory fitness				Motor skills			
	B	SE	q^c	90% CI	B	SE	q^c	90% CI
Random intercept	3.63	0.46	<0.01	2.88–4.39	0.68	0.23	<0.01	0.31–1.05
Corresponding baseline score	0.79	0.03	<0.01	0.74–0.83	0.79	0.03	<0.01	0.79–0.83
Sex ^a	–0.31	0.10	<0.01	–0.46 – –0.15				
SES					0.06	0.02	0.02	0.02–0.10
BMI	–0.12	0.02	<0.01	–0.16 – –0.09	–0.03	0.01	0.01	–0.05 – –0.01
Aerobic exercise group ^b	0.12	0.28	0.66	–0.34–0.59	0.11	0.11	0.66	–0.07–0.29
Cognitively engaging exercise group ^b	0.35	0.28	0.33	–0.11–0.82	–0.11	0.11	0.33	–0.29–0.08
<i>Random effects</i>								
Variance classes	0.49	0.12	<0.01		0.07	0.02	<0.01	
Variance students	1.39	0.07	<0.01		0.31	0.02	<0.01	
Deviance		2529.04				1164.31		
Deviance covariates model		2530.61				1167.21		

^{a,b}Respectively boys and control group were the reference categories; ^csignificance after FDR correction; Chi-squared test between aerobic exercise group and cognitively engaging exercise group: cardiorespiratory fitness: $\chi^2(1) = 0.51$, $q = 0.48$, Motor skills: $\chi^2(1) = 2.89$, $q = 0.18$; SES = socioeconomic status; CI = Confidence Interval.

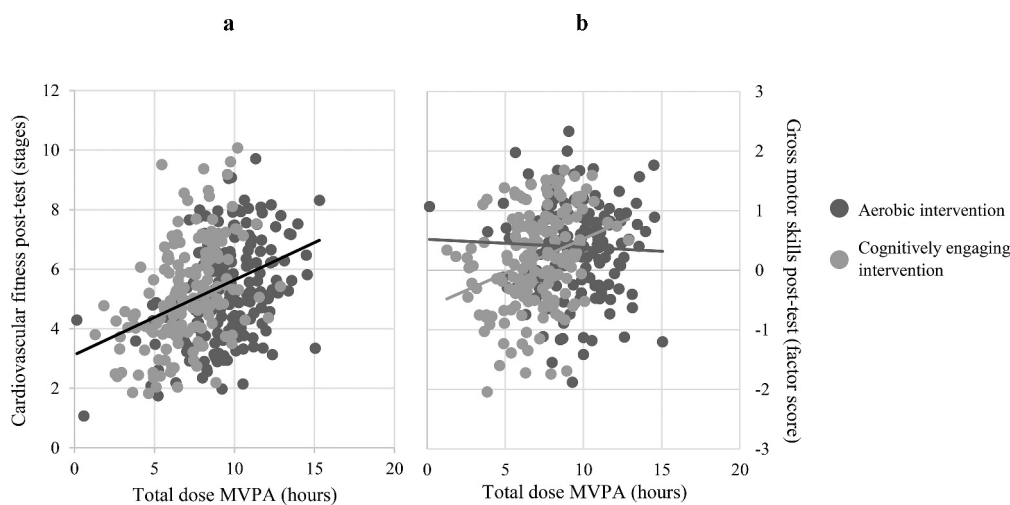


Figure 2. The effects of the total dose of moderate-to-vigorous physical activity (MVPA) on cardiovascular fitness (a) and gross motor skills (b). Cardiovascular Fitness is shown adjusted for sex, baseline score, BMI, condition, and total dose of MVPA. Gross motor skills score is shown adjusted for socioeconomic status, BMI, baseline score, condition, total dose of MVPA, and the interaction between study condition (aerobic exercise vs cognitively engaging exercise) and the total dose of MVPA.

within the intervention groups and is consistent with previous studies showing that the higher the amount of MVPA, the greater the benefits on cardiorespiratory fitness (Janssen & LeBlanc, 2010; Parikh & Stratton, 2011).

There were no significant effects of the interventions on motor skills. This is in contrast to our hypothesis and to the findings in the meta-analysis by Morgan et al. (2013) showing that school-based interventions significantly improved motor skills in youth when developmentally appropriate motor skill learning experiences are delivered by physical education teachers (Ashy, Lee & Landin, 1988; Gallahue & Donnelly, 2007). There were no significant effects of the interventions on motor skills. This is in contrast to our hypothesis and to the findings in the meta-analysis by Morgan et al. (2013) showing that school-based motor skill interventions significantly improved motor skills in children when developmentally appropriate motor skill learning experiences were delivered by physical education teachers (Ashy, Lee & Landin, 1988; Gallahue & Donnelly, 2007). The studies included in the meta-analysis by Morgan et al.

(2013) developed interventions with many opportunities for individual practice and self-testing activities. In our cognitively engaging intervention, the main focus was on activities and games with high cognitive engagement. Although the intervention consisted of activities in which children had to perform and apply motor tasks in cognitively engaging activities, there was less focus on individual practice and feedback on their motor skills, which could explain the lack of significant effects. Furthermore, most studies that have investigated effects of motor skill interventions used process-oriented measures for motor skills. We used product-oriented measures for motor skills, which might explain why we could not replicate the previous findings.

However, we found a positive dose-response relation between MVPA and motor skills for children in the cognitively engaging intervention. This may indicate that children that are more involved in the games and exercises in the cognitively engaging intervention have more opportunities to practice motor skills, which in turn, results in better motor skills (Willingham, 1998).

Strengths, limitations and directions for future research

Strengths of this study were the development of two interventions, the large sample size and the recruitment of physical education teachers that delivered the interventions to minimize the load for classroom teachers.

A limitation of this study was the assessment of motor skills. We used the KTK and BOT-2 to obtain motor skills, which are isolated motor skill assessments. However, the games and exercises in the cognitively engaging intervention challenged children to alter and combine motor skills in complex environments. We used the KTK and BOT-2 because these product-based tests are less sensitive to assessor experience and subjectivity as compared to process-oriented measures. Furthermore, the reliability and validity of these tests are adequate (Bruininks, 2005; Deitz et al., 2007; Kiphart & Schilling, 2007). Circuit-based assessments have recently emerged as a dynamic method, but these tests are more sensitive to assessor experience and the validity and reliability of circuit-based assessments need to be further investigated (Bardid et al., 2019). Furthermore, the absence of an indication for the amount of practicing or applying motor skills so dose-response effects between practicing motor skills and motor skill performance could not be considered. This is important for future research, because the amount of repeated practice and interactions with the environment is important in the development of motor skills (Willingham, 1998). Thirdly, MVPA was only measured in two of the physical education lessons. Therefore – although we measured the two most representative lessons – the dose of MVPA in the intervention groups was only an estimation of the time that children actually were engaged in MVPA.

Practical implications

The results of this study have practical implications that need to be addressed. First, the results implicate that the time in MVPA during physical education lessons can be increased by implementing games and activities with the main aim to increase MVPA. Second, the individual exposure to physical activity is an important factor that influences the effectiveness of an intervention. Therefore, it is important to challenge *all* children to engage highly in MVPA during physical activity interventions.

Conclusions

In conclusion, no main effects of the aerobic intervention and the cognitively engaging intervention on cardiorespiratory fitness and motor skills were found in grades three and four primary school children. The intervention effects did not depend on baseline levels of cardiorespiratory fitness or motor skills. However, this study showed that children with a higher dose of MVPA demonstrated higher cardiorespiratory fitness after both interventions and enhanced motor skills after the cognitively engaging intervention. The results of this study highlight that individual exposure to physical activity is an

important factor that influence the effectiveness of interventions.

Clinical trial registry

Learning by Moving, registration number NL5194.

Disclosure statement

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